



Meso-to-microscale modelling of the ABL: an open-science approach

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Objectives of New European Wind Atlas

04/2015 – 04/2019

1. Publication of the **European Wind Atlas** database via a web interface
2. Dataset of **high-fidelity experiments**
3. Methodologies for WRA based on a **mesoscale to microscale** model-chain.
4. **V&V framework** based on the experimental campaigns and means to quantify the **uncertainties** of the wind atlas.

@mesoscale

NEWA database of mesoscale wind climate

- ✓ 30-year WRF down to 3 km resolution + downscaling to 50 m using WAsP (generalized wind)
- ✓ Mesoscale multiphysics ensemble (UQ)
- ✓ **Open source code** of the WRF configuration.

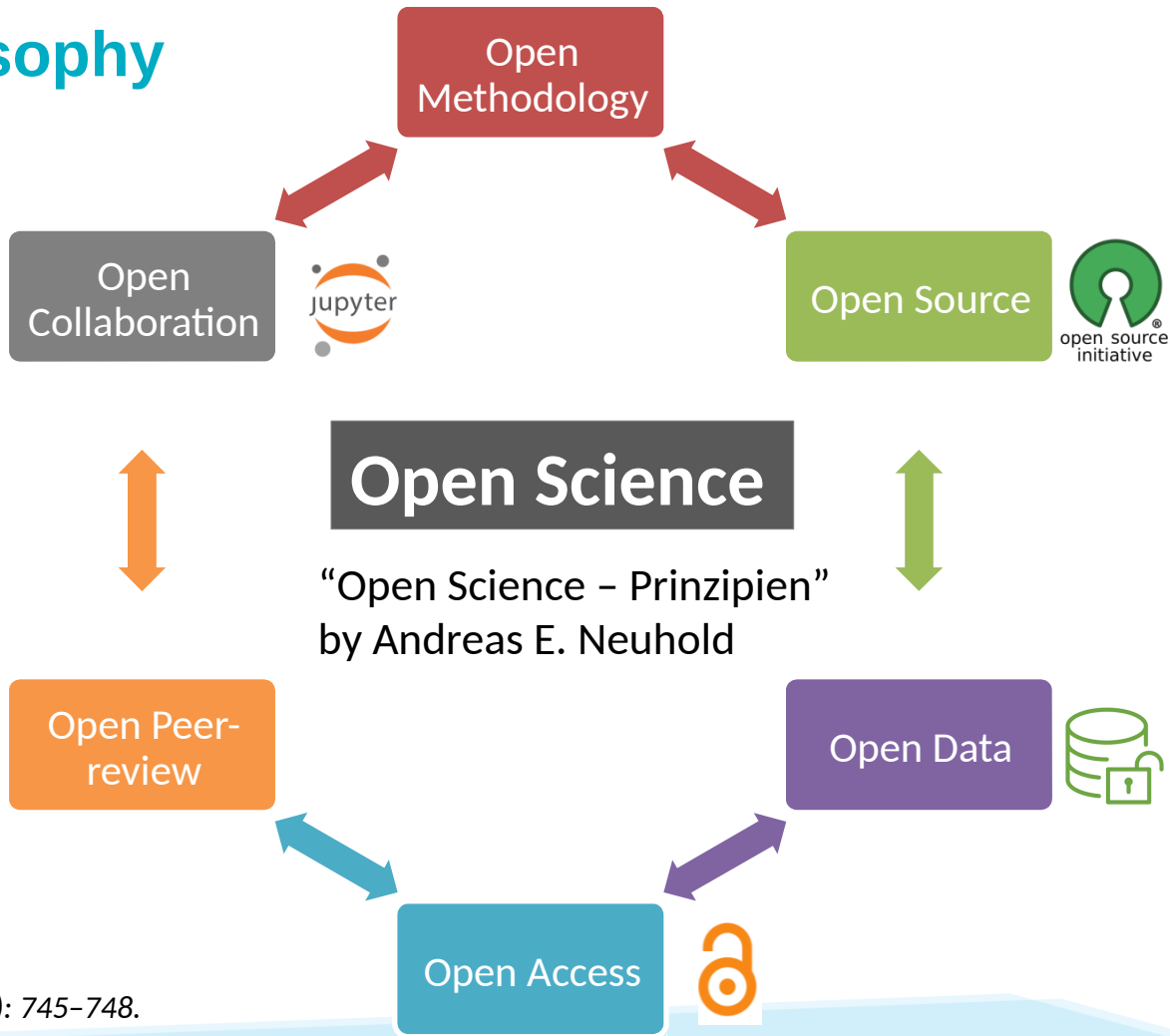
@microscale

Design methodology for CFD models (RANS or LES)

- ✓ **Open dataset** of surface-layer characterization based on aerial lidar scans of vegetation canopy
- ✓ **Open source** CFD model based on OpenFOAM (CFDWind3)

Open science philosophy

*“A philosophy of making scientific research and its dissemination accessible to all levels of an inquiring society”**



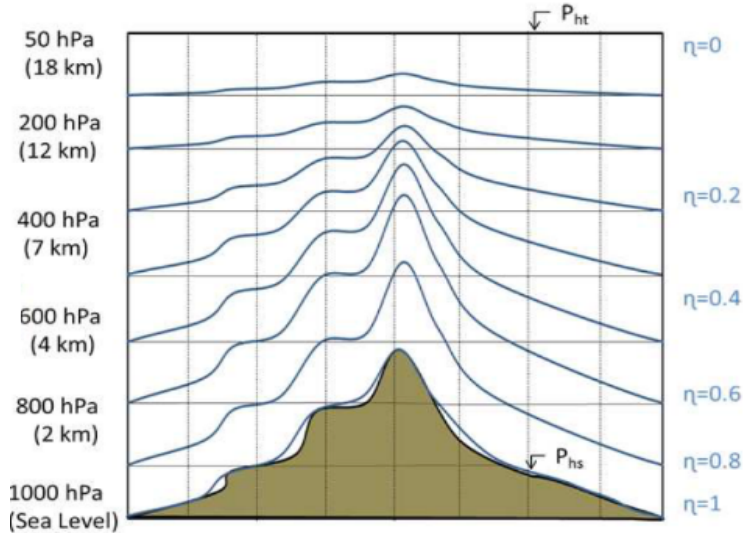
Why this should be important for industry:

- Transparency
- Credibility
- Standardization

* Woelfle M. et al (2011). Nature Chemistry. 3 (10): 745–748.

Challenge: Characterization of wind flow of sites with strong thermal and mesoscale variability.

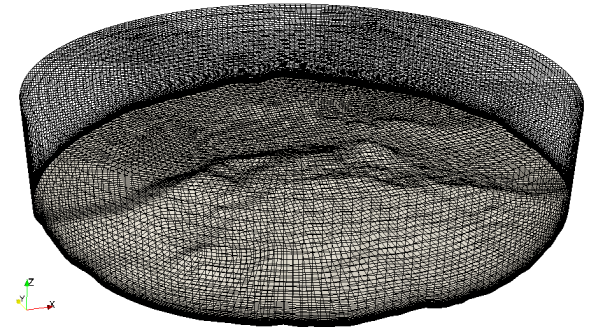
New method : Coupling meso and microscale model through the tendencies



WRF domain



CFD domain

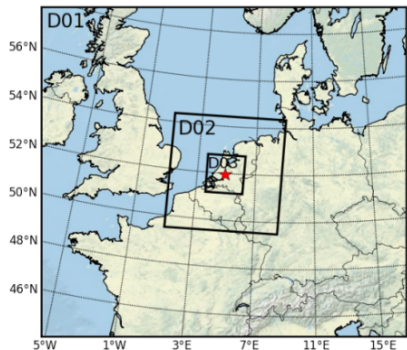


**Volumetric force from
WRF into CFD**

$$\left(\frac{\partial P}{\partial x_i}, U_i \frac{\partial U_j}{\partial x_i} \right)$$

- Holtslag AAM *Boundary-Layer Meteorol* 152 127-132
- Sanz-Rodrigo J, Matthew Churchfield, and Branko Kosovic. *Wind Energ. Sci.*(2017), 2, 35-54

What are tendencies?: Volumetric forces



WRF simulation over the Netherlands for:
2006-07-01 to 2006-07-02

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WRF sensitivity experiments for the mesoscale NEWA wind atlas production run

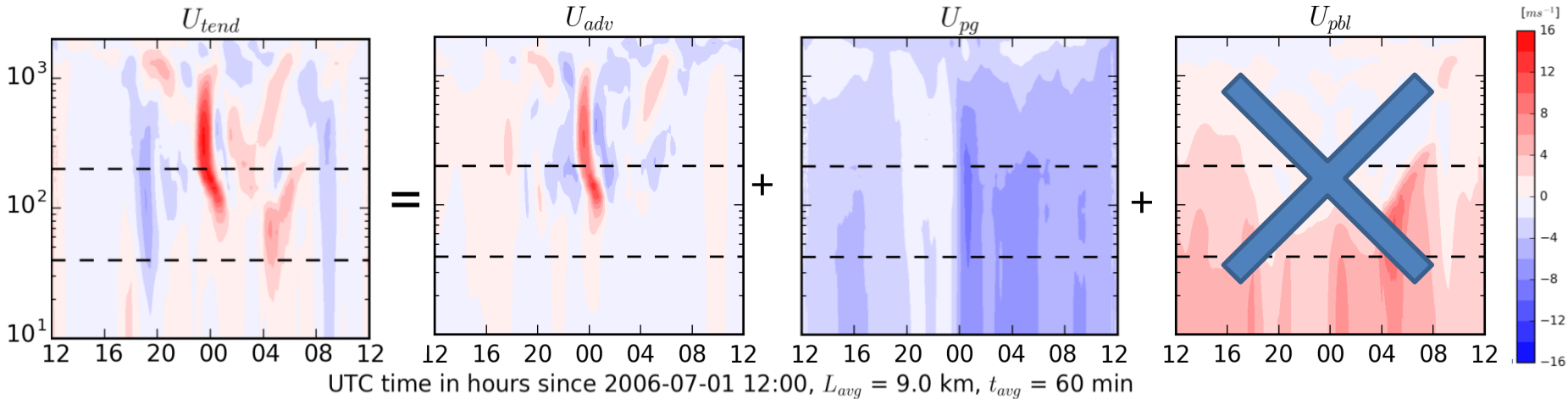
Andrea Hahmann (1), Björn Wiha (2), Tija Sile (3), Martin Dörenkaemper (4), Stefan Söderberg (5), Jorge Navarro (6), Grégoire Leroy (7), Arnan Folkh (8), Elena Garcia Bustamante (9), and Fidel Gonzalez-Rouco (9)
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Total tendencies

Advected wind

Geostrophic wind

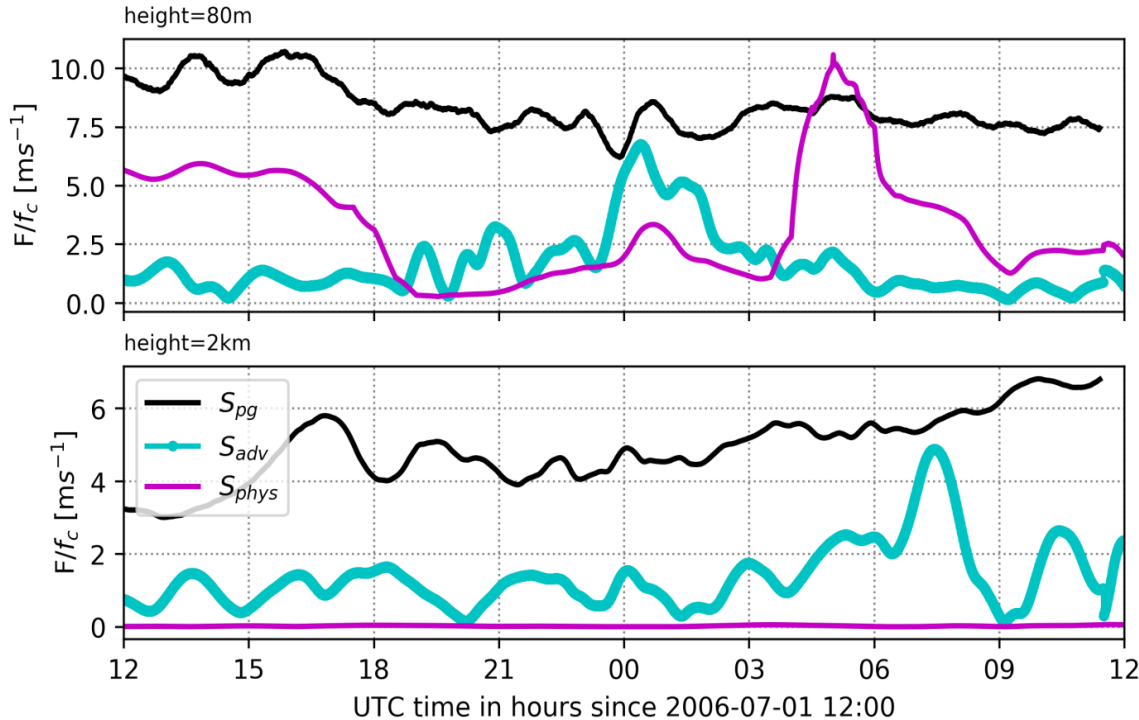
PBL schemes = phys



What are the tendencies?: volumetric forces

2006-07-01 to 2006-07-02

Tendencies (volumetric forces)



Comparison between force terms of the momentum budget:

- Pressure gradient **S_{pg}**,
- Advective momentum **S_{adv}**
- PBL parameterization term **S_{phy}**

One-way offline coupling of WRF with CFD model

The CFD model

- RANS turbulent closure modified as Sogachev et al. (2012)
- Based **CENER's CFD model (CFDWind3)** built on top the Open-Source CFD tool-kit OpenFOAM
- Transient
- No humidity equation, no radiation nor phase changes

The CFD model receives from WRF:

- Pressure gradient and advective terms of momentum (Forces) and energy temperature
- Initial conditions from WRF: velocity and temperature
- Wall temperature: WRF Skin temperature

- See Sanz-Rodrigo et al. (2017). *Wind Energ. Sci.*, 2, 35-54, 2017

Open  FOAM

The Open Source CFD Toolbox

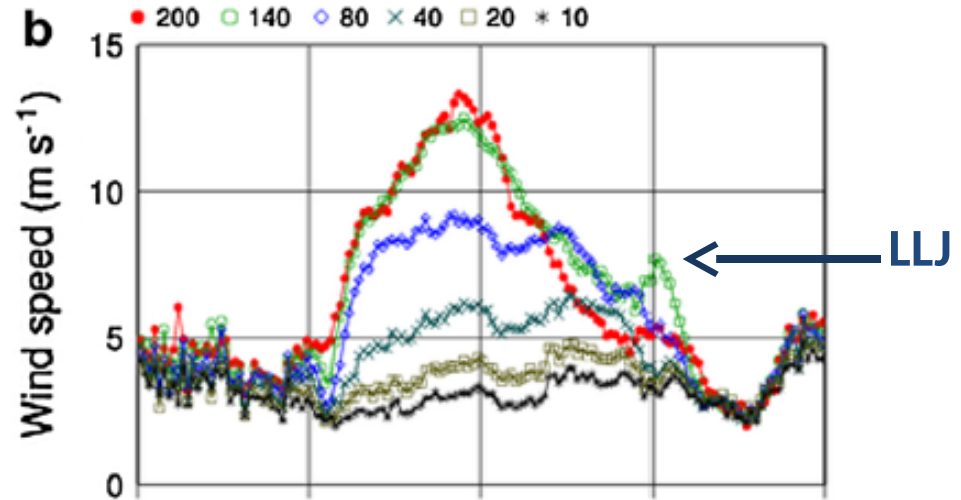
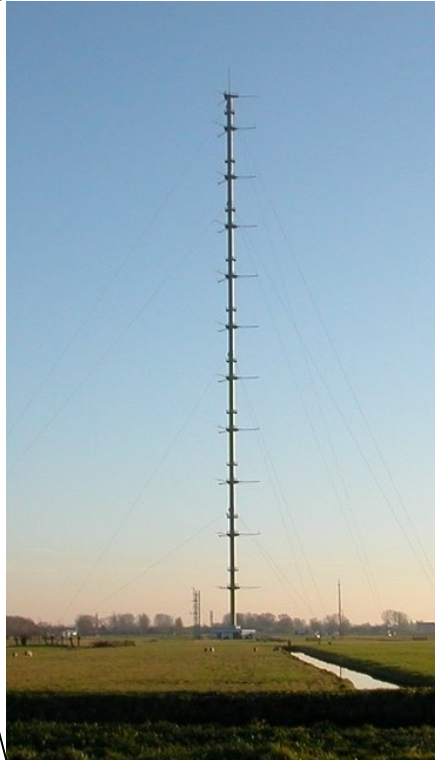
Open methodology

Open Source

Proof-of-concept: GABLS3 diurnal cycle

GABLS3 = GEWEX Atmospheric Boundary Layer Studies

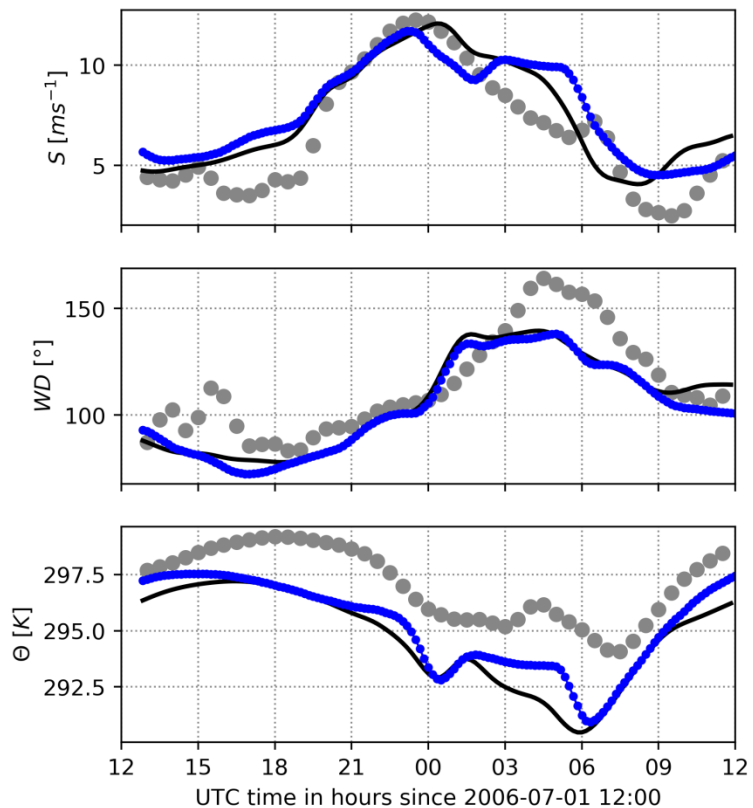
Cabauw met mast, Netherlands (2006-07-01 to 2006-07-02)



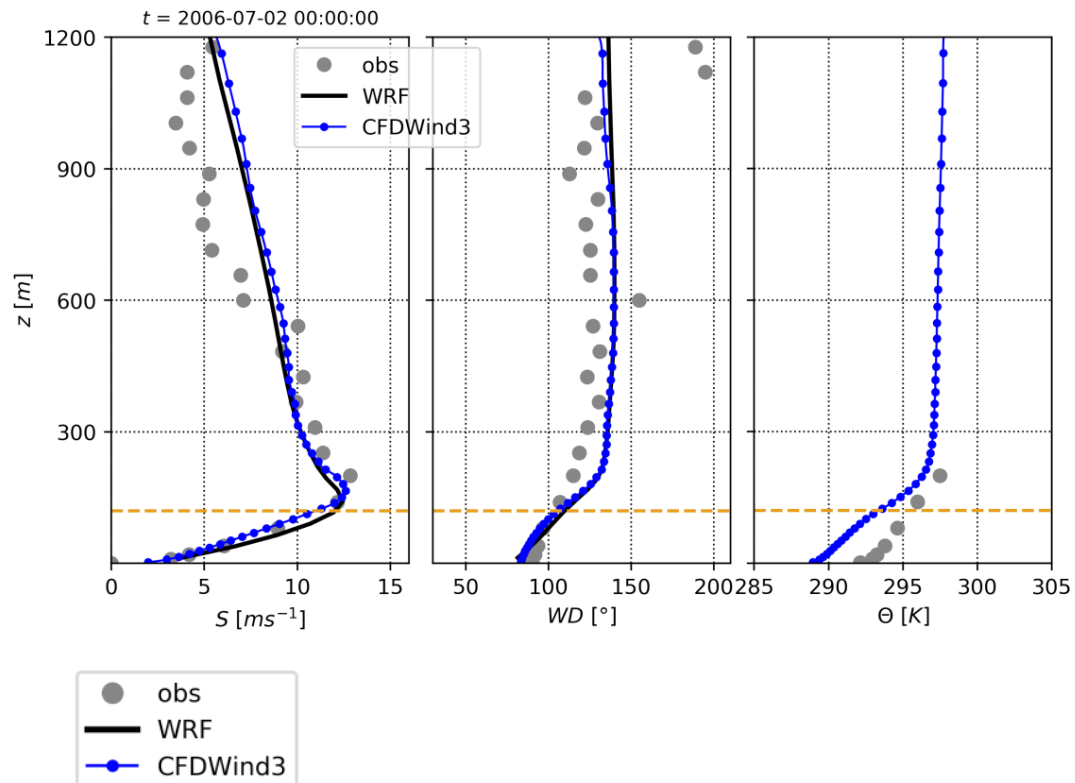
Bosveld, F.C., Baas, P., van Meijgaard, E. et al. *Meteorol* (2014) 152: 133

Proof-of-concept: Results of the diurnal cycle during GABLS3 episode with CFDWind

Results at 120m above ground



Vertical profiles



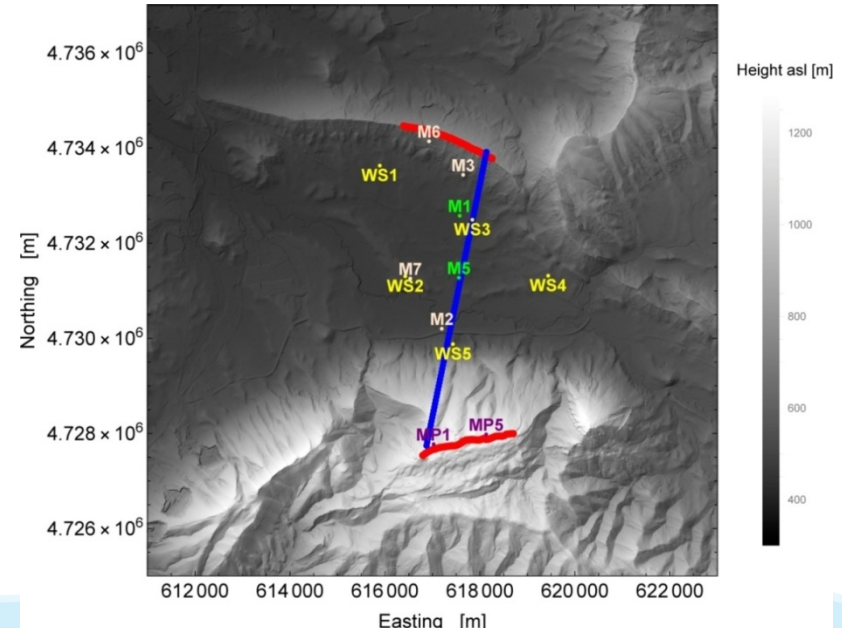
Alaiz (ALEX17) Full-Scale Experiment

- 6 month period of intensive campaign
- 12+ moth period for masts and Sodar



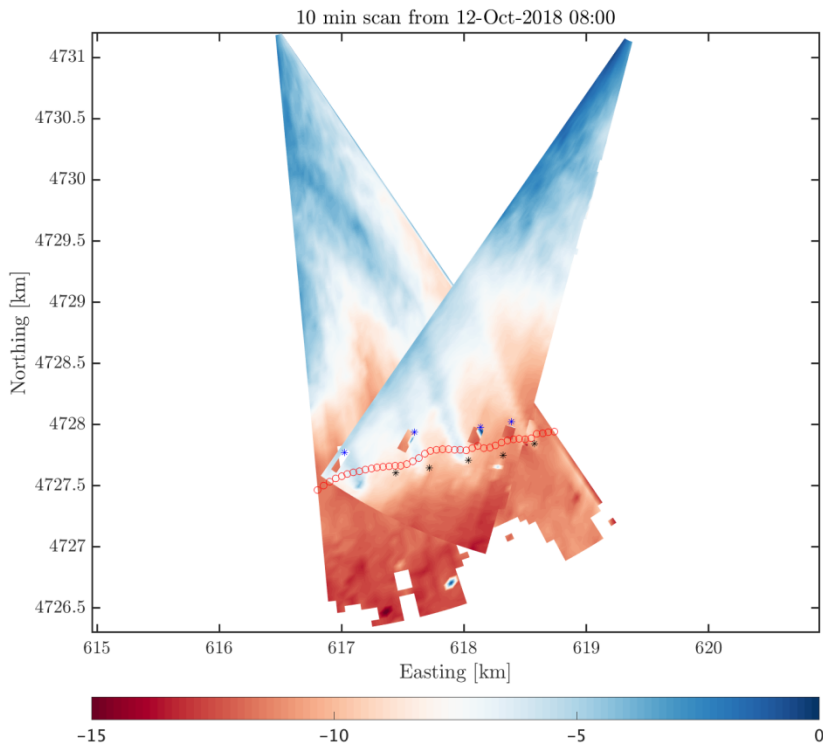
Measurement equipment

- 5 long-range scanning lidars
- 1 profiler
- 6@80m met masts (4 sonics +2 cups)
- 10 surface flux stations
- CENER's test site (4@118m masts)
- Sodar Wind-RASS

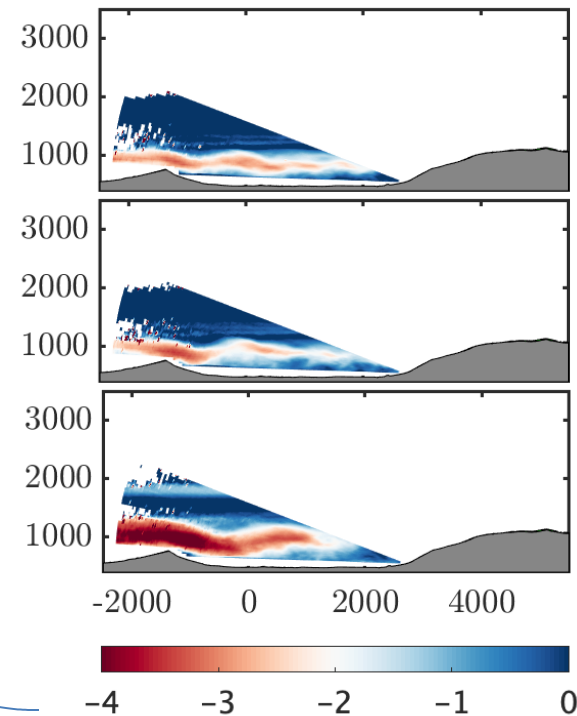


ALEX17 objectives: Better understanding of complex flow dynamics on mountain range sites.

Wind turbine wakes interaction in complex terrain



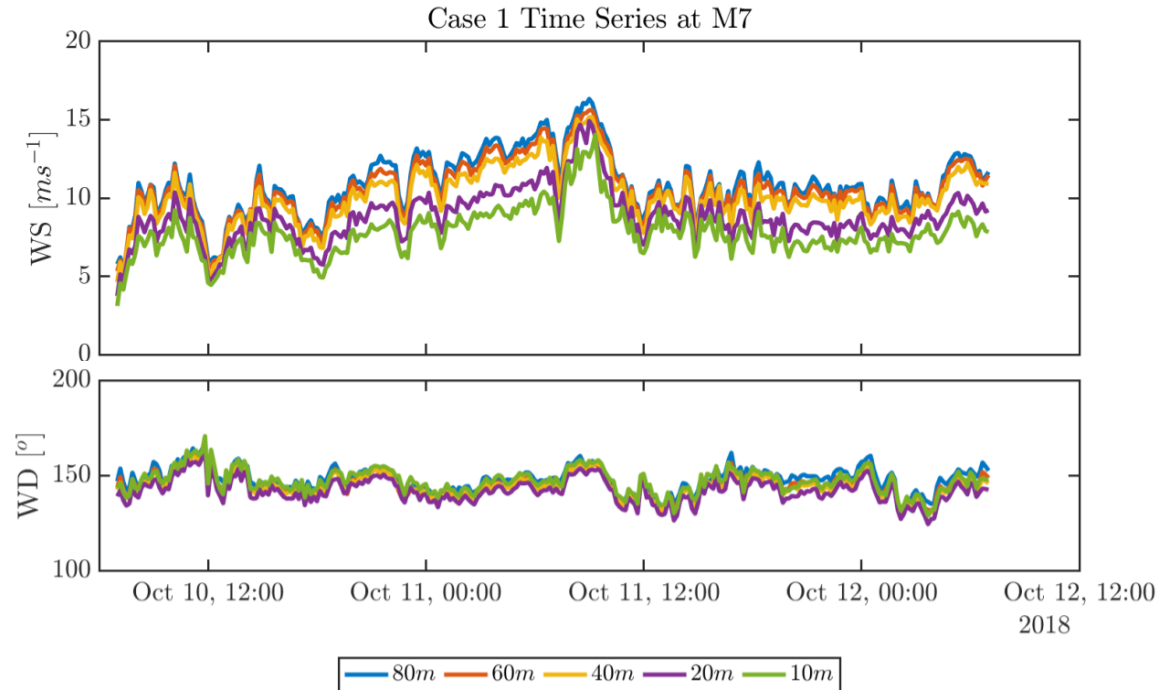
Evolution of lee waves



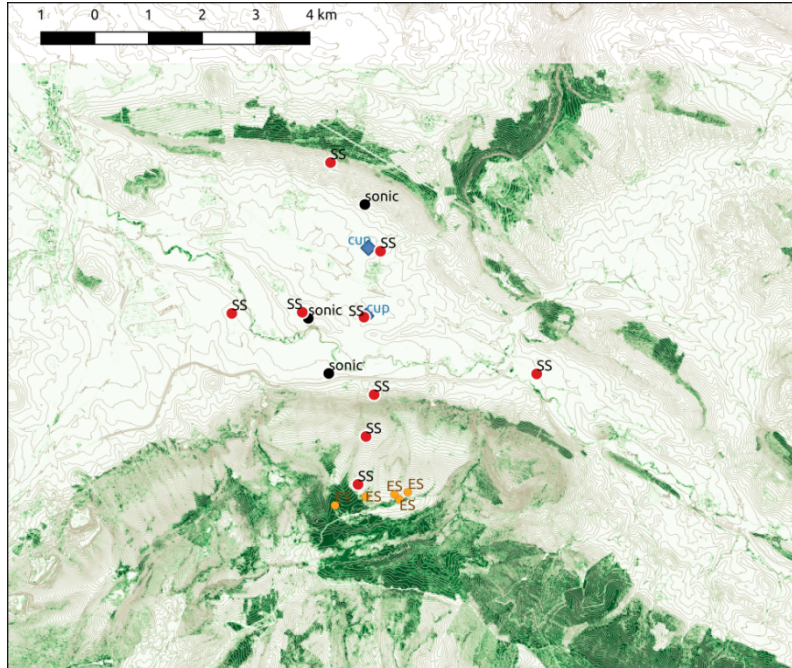
ALEX17 objectives: Development and Uncertainty Quantification of numerical models.

Verification & Validation of numerical models through a set of benchmarks:

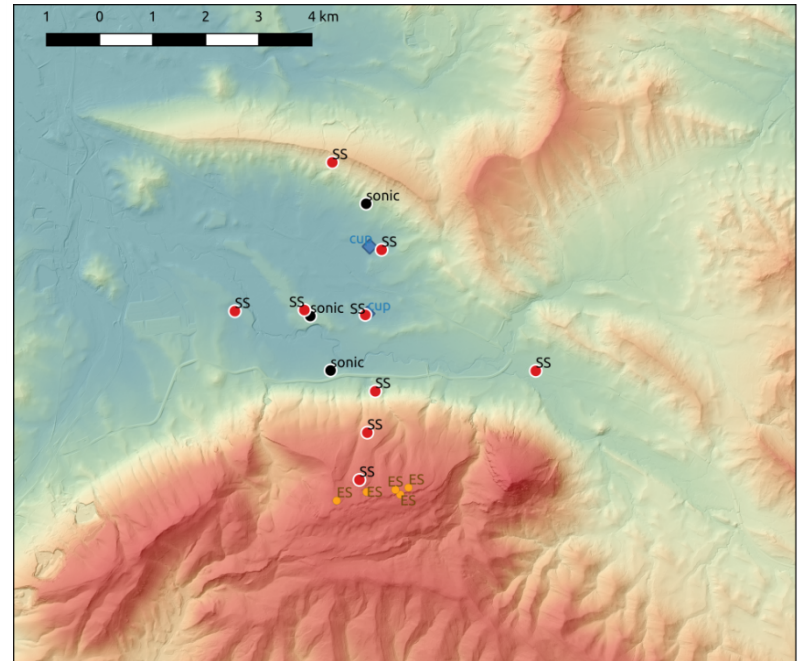
1. A particular weather episode (diurnal cycles (48h from 10-10-2018 6:00 UTC)
2. Annual integration (Jun/2018 – Jun 2019) case for AEP calculation.



High-resolution data of forest height and Leaf Area Density*



High-resolution (2m) data of terrain elevation*



*The land surface data was generated from airborne Lidar systems provided by TRACASA (<https://tracasa.es>)

** The forest height and PAD data were generated by Ebba Dellwik DTU (Boudreult et al. 2015. Agr Forest Meteorol 201 (2015) 86–97)

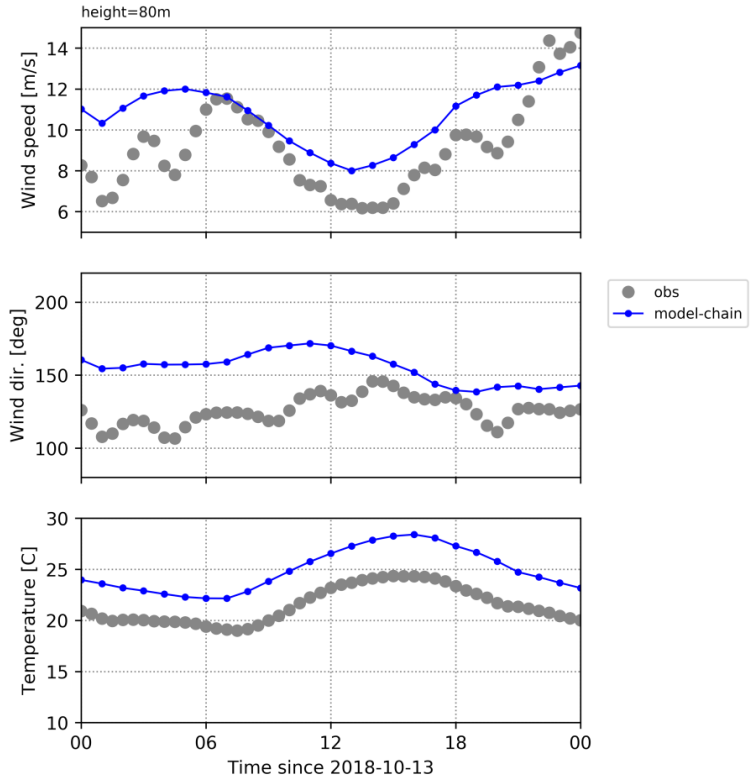
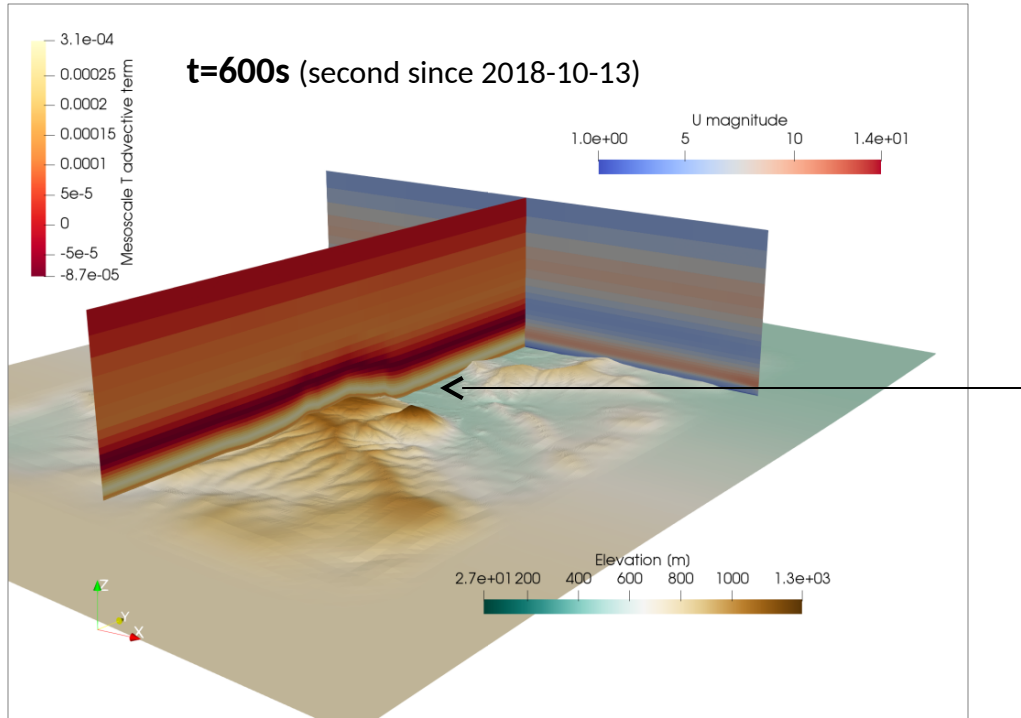
Open methodology

Open Source

Open Data

A glimpse of model-chain results

Comparison of model and measurements at Elortz1 mast at 80m height



Open methodology

Open Source

Open Data

Open Access

Publication of the new method, results and V&V exercises are published in open-access journals

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A methodology for the design and testing of atmospheric boundary layer models for wind energy applications

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- <https://www.wind-energ-sci.net/2/35/2017/>
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- <https://iopscience.iop.org/article/10.1088/1742-6596/854/1/012037>

Final comments and conclusions

- ✓ A method for addressing the meso-microscale coupling was presented.
 - More realistic physics.
 - The method is characterized by a **volumetric forcing as opposed to idealized forcing**.
 - The V&V of the method/CFDWind3 model is being carried out with ALEX17 experiment.
- ✓ The whole procedure is framed by the open-science philosophy: the method is published in open-access journals, the model-chain implementation is open-source and the validation data is open.
 - The whole philosophy makes research more **rigorous, reproducible and transparent**.
 - Clear benefits of open-science for industry is **standardization** and building **credibility** in new methods and their V&V procedures.
 - For developers of proprietary software, this is also creates a framework for model **development, validation and building trust** in their solutions.

ALEX17 benchmark will be open to all interested participants. Check at:

[https://
thewindvaneblog.com/newa-meso-micro-challenge-phase-2-complex-terrain-98efeb03a23a](https://thewindvaneblog.com/newa-meso-micro-challenge-phase-2-complex-terrain-98efeb03a23a)

The experimental data sets are stored in the NEWA server.

The open-source model is available at the following git repository and it is intended to be a live code.

<https://github.com/iat-cener/CFDWind>

The evaluation methodology of the benchmarks as well as the data processing of the experiment are also available in public domain at the following links.

<https://github.com/windbench/gabls3>

<https://github.com/windbench/NEWAMesoMicroChallengePhase1>

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- The Swedish Energy Agency (Sweden)
- The Scientific and Technological Research Council of Turkey (Turkey)

